Trends in Ground-Water Sampling: A Comparison of Ground-Water Sampling Methods

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Presentation and Discussion Topics

- History of traditional purging and sampling methods
- Limitations of traditional purging methods
- Purging evolution: Low-flow purging and sampling
- Advantages & limitations of Low-flow purging and sampling
- Passive and No-Purge sampling methods and devices
- Advantages & limitations of Passive and No-Purge methods
- Monitoring well bias and limitations
- Multi-level sampling systems – advantages and limitations
- Summary and Q&A Session
Ground Water Sampling Methods: An Historical Overview

1960s
The earliest ground-water sampling methods were borrowed from the water well industry; most sampling was done from water supply wells. The late 1960s saw the first recommendations for well purging prior to sampling from water quality monitoring wells.

1970s
Early research led to introduction of the concept of well-volume purging to produce samples representative of the formation water. Purging and sampling was done primarily with bailers, common electric submersible pumps and centrifugal pumps.

1980s
Stronger environmental regulations resulted in an increasing number of site investigations for soil and ground water contamination. Advances in analytical methods began to drive improvements in sampling methods, with a greater emphasis on sample accuracy and precision.

1990s
Industry sought an alternative to the high cost of monitoring a large number of wells on a continuous basis. The introduction of Risk-Based Corrective Action and Monitored Natural Attenuation required more accurate and precise sampling data.
Well Purging/Sampling Approaches

• Traditional well-volume purging
  – 3-5 well volumes – pumped or bailed
  – Evacuation of low-yield wells, sample on recovery

• Purge to stabilization of indicator parameters
  – No guidelines on flow rate, pump position, drawdown, etc.

• Low-flow purging and sampling
  – Purge to parameter stabilization, but flow rate based on well yield

• Passive and No-purge Sampling
  – Samples are taken from well screen/borehole without purging
  – Sample after equilibration of borehole flow and water chemistry

• Multi-Level Sampling Systems
  – Discrete short-screened wells or commercial MLS systems
Early purging research resulted in guidelines to remove “stagnant” water from the well

- The “rule of thumb” was 3 to 5 well volumes prior to sampling to get formation water.

- “Low-yield” wells were evacuated and sampled upon recovery, typically within 24 hours.

- Little concern was given to how purging protocols and devices (e.g., bailers) affected the chemistry of ground water samples.
What does the sample represent using traditional purging methods?

- Water from other vertical zones
- Normally Immobile NAPL Microglobules
- Normally Immobile Colloids and Sediment Elevate Turbidity
- Water Chemically Altered by Gas Exchange
Limitations of Traditional Well Purging Practices

- High purge volumes can cause underestimation due to dilution or overestimation due to induced plume migration, contaminant mobilization and increased sample turbidity.
- Dewatering lower-yield wells causes losses of VOCs, affects DO and CO₂ levels, and increases sample turbidity.
- Excessive drawdown can cause overestimation (“false positives”) from soil gas infiltration or from mobilization of soil-bound contaminants in the overlying formation or smear zone.
- Purge water generated can be tens or hundreds of gallons from each well, with the associated handling and disposal costs.
Purging with Bailers and Inertial Lift Pumps

- Stagnant water mixes into the sampling zone, requiring extensive purging to obtain formation water.
- Surging action increases turbidity, which can affect both metals and some organic compounds.
- Insertion of the bailer causes aeration that can reduce VOCs and dissolved metals.
- Difficulty in reproducing the same purging rate leads to significant data imprecision and inaccuracy.
High-Rate/High Volume Purging with Pumps

• Excessive drawdown pulls stagnant water into sampling zone and mobilizes smear zone contaminants.
• Water from chemically distinct zones above and below the screened zone are pulled into the borehole.
• Less accurate samples result from effects on volatiles, turbidity, mixing and dilution.
Bailing and High-Rate Pumping Elevate Turbidity

- Sample filtration adds cost and time in field or laboratory
- If filtration is not permitted, turbidity can greatly elevate concentrations of metals and some organics (e.g., PAHs) where they are bound to soils
- The chemistry of turbid samples that have been filtered to remove excess turbidity is not the same as that from low turbidity samples
Filtering samples to remove turbidity can bias results through sorption, leaching, oxidation and pass-through.
Effect of turbidity on metals values  
(from Heidlauf and Bartlett, 1993)

Turbidity can have a significant effect on the concentrations of metals in unfiltered samples. The values from turbid samples that have been filtered can be measurably higher or lower than values from low turbidity samples.

<table>
<thead>
<tr>
<th>Sampling method</th>
<th>Low-flow pump Unfiltered 0.5 NTU</th>
<th>Open-top bailer Unfiltered &gt; 100 NTU</th>
<th>Open-top bailer Filtered, 0.45µ 0.6 NTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample type and Turbidity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>2</td>
<td>29</td>
<td>2</td>
</tr>
<tr>
<td>Aluminum</td>
<td>57</td>
<td>5490</td>
<td>84</td>
</tr>
<tr>
<td>Cobalt</td>
<td>9</td>
<td>44</td>
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<tr>
<td>Copper</td>
<td>9</td>
<td>22</td>
<td>19</td>
</tr>
<tr>
<td>Iron</td>
<td>21</td>
<td>4920</td>
<td>7</td>
</tr>
<tr>
<td>Manganese</td>
<td>2</td>
<td>899</td>
<td>3</td>
</tr>
<tr>
<td>Nickel</td>
<td>12</td>
<td>33</td>
<td>29</td>
</tr>
<tr>
<td>Vanadium</td>
<td>7</td>
<td>31</td>
<td>13</td>
</tr>
</tbody>
</table>
High sample turbidity results in artificially high PAH values, while low-flow samples with low turbidity represent the true mobile contaminant load.
Purging 3-5 well volumes can generate hundreds or possibly thousands of gallons of purge water that often must be collected for treatment/disposal if found to be contaminated.
Limitations in traditional purging methods led to the evolution of low-flow purging

• Low-flow purging and sampling is a methodology that reduces disturbance to the well and aquifer typically caused by bailing or high-rate/high-volume purging.

• Low stress = low turbidity, improved sample accuracy, reduced purge volumes.

• Contrary to popular belief, the development of the low-flow purging approach was based on a need to control artifactual turbidity, not to reduce purge water volumes.
Low-Flow Purging & Sampling

• Low pumping rate minimizes drawdown, mixing and formation stress, isolates stagnant water above well screen.
• Low stress = low turbidity, improved sample accuracy, reduced purge volumes.
• Samples represent naturally mobile contaminants, not stagnant water in the well or mobilized contaminants.
• Purge volume is based on stabilization of indicator parameters measured during purging.
Lower flow improves sample quality

Low-flow purging and sampling controls turbidity and delivers higher quality samples - a clear advantage.
Effect of low-flow sampling on data accuracy and precision

Island County Landfill - Unfiltered Metals Concentrations - Well E2S

- Wells purged and sampled with bailers; high turbidity (>100 NTU)
- Purged with pump and sampled with bailers; varying turbidity (30-50 NTU)
- Changed to low-flow sampling with dedicated bladder pumps
What Does a Low-Flow Sample Represent?

Empirical studies and modeling simulations show that the entire well screen contributes to the sample:

- Flow into screen is controlled by the geology near the well, regardless of pump position; high K zones contribute more water.
- The actual zone monitored is longer than the length of the screen.
- Same for 5, 10, and 20 foot screens.
- Applies to both fully submerged screens and screens intersecting the water table.

Varljen, et al. 2006
Reduced Purge Water Handling/Disposal

Traditional Well Volume Purging

Low-Flow Purging
Advantages of Low-Flow Sampling

• Low-flow is a consistent, performance based standard for purging, rather than an arbitrary rule of thumb.

• It documents purging process for every sample, overcoming factors that can affect required purge volume.

• Low-flow sampling can reduce sampling costs:
  – Direct cost savings - reduced purge water handling & disposal, reduced purging time (in some wells).
  – Sample Quality - reduced turbidity, more accurate dissolved concentrations, and a better estimate of the true mobile contaminant load
  – Indirect cost savings - improved data accuracy and precision (fewer false statistical “hits”); better data = better decisions.
Limitations of Low-Flow Sampling

- Low-flow purging won’t work in very-low-yield wells where the pumping water level won’t stabilize even at very low flow rates (practical lower limit is 50-100 mL/minute).
- In low-yield wells, purging times can be longer than traditional methods of well volume purging or well evacuation.
- Bottle filling can also be slower when maximum purge rate is low, sometimes taking longer than purging the well.
Passive and No-Purge Sampling: The next evolutionary step?

- Over the past decade, researchers and manufacturers have studied sampling wells without purging.
- The methodology is based on the concept that ambient groundwater flow through the well screen would maintain an approximation of the groundwater chemistry within the screen zone of the well.
- Samples represent the discrete interval within the screen where the samplers are placed or activated, rather than a flow-weighted average of the screen zone (unless ambient mixing occurs).
- Several passive or no-purge samplers can be deployed at various depths in the well screen in order to identify any contaminant stratification within the water column.
Types of Passive Samplers
(from ITRC DSP-4)

• **Diffusion Samplers**: analytes reach and maintain equilibrium via diffusion through membrane or small pores in sampler body

• **Equilibrated Grab Samplers**: remain in the well before sampling, then collect a whole-water sample when activated

• **Accumulation Samplers**: rely on diffusion and sorption to accumulate analytes in sampler
Polyethylene Diffusion Bag Samplers

Cross Sectional View

Typical PDB sampler is 1-2 feet in length
Certain VOCs, primarily chlorinated and aromatic hydrocarbons, will diffuse through the polyethylene bag.
Most other common analytes, such as metals, pesticides, semi-volatiles and some volatiles can’t diffuse into the bag.
Passive Diffusion samplers remain in the well until equilibrated with the water chemistry; samples are decanted upon retrieval.

Rigid Porous Polyethylene Sampler (RPPS) must be shipped wet, holds 80-100 mL of sample maximum.

Polyethylene Diffusion Bag (PDB) can be filled in lab or field, holds 75-350 mL of sample or more.
Equilibrated Grab Samplers can be used for a wider range of target analytes. Samples are either decanted at the well head or the sampler is shipped to the laboratory for analysis.
No-Purge/Passive Sampling Advantages

- Little or no waste water generated.
- Low initial cost/capital investment for most designs.
- Easy to deploy and recover samplers in most wells (deep wells can be challenging).
- Minimal amount of field equipment is required.
- Some samplers are disposable, so no decontamination is needed between wells.
- Can provide information on contaminant stratification within the well if present.
- Most samples are not subject to interference from turbidity.
No-Purge/Passive Sampling Limitations

- All samplers are limited by analytes (e.g., PDB – VOCs only) or sample volume, limiting their use for some applications.
- Must identify sufficient ambient flow in the screen zone through use of borehole flow meters or other methods. As an alternative, guidance suggests comparing passive/no-purge results to historical data or to traditional purge-and-sample methods.
- Target zone for routine monitoring determined through analysis of multiple samplers; improper placement can result in significant concentration differences. Presence of stratification may require routine deployment of multiple samplers, reducing or eliminating cost savings due to increased analytical expense.
- Collecting background water chemistry parameters (pH, DO, etc.) may requires a separate sampling step for some samplers.
- Resampling to verify questionable data requires redeployment and waiting a minimum of days or weeks.
How do low-flow sampling and no-purge/passive sampling compare?

• Studies comparing low-flow and no-purge/passive sampling show good correlation in some wells but significant differences in others. This may be the effects of contaminant stratification in the well, ambient vertical flow/mixing, or the limitations of some passive sampling devices.

• Cost saving with no-purge/passive sampling are typically based on a single sampling point. If multiple passive/no-purge samplers are used, sampling cost savings are quickly offset by increased analytical costs.

• The biggest difference is in what the sample represents. Low-flow represents a flow-weighted average of the well screen, while a no-purge/passive sample may represent either a depth-discrete sample of the well screen (but not necessarily the surrounding formation), or may represent some undefined average value of the screen zone due to ambient vertical flow and mixing within the well.
Multiple PDB samplers vs. Low-Flow Sampling at Well 18S

- “These data imply that the low-flow sampling results can be a mixture of waters within the screened interval”
- Note concentration differences of ± 150% with passive samples over an interval of 7 feet within the well screen.

USGS Fridley, MN (May 2000)
The REAL question is…

What is the **WELL** telling us?
Hydraulic head differences drive flow in the subsurface. Whenever a well connects two regions having different heads, local ambient flow occurs. ▶ Ambient flow is downward in recharge areas and upward in discharge areas.
Transport Simulation Results Within a Well
(from Elci, et al., 2001 - GWMR)

\[ t = 20 \text{ days} \]

constant
C = 100 mg/L
How Common Is Measurable Ambient Flow?
(from Elci, et al., 2001)

- 142 wells at 16 sites in 12 states
- 73% of the cases had measurable amounts of ambient flow
- Range of measured ambient flow at all sites: 0.01 L/min - 6.2 L/min
Monitoring Well Biases

• Pumped samples are flow-weighted average concentration values of the screen zone and beyond. **What you screen is what you get!**

• Results depend on position and length of screens relative to contaminant pathways.

• Wells can redistribute contaminant mass in the aquifer when vertical gradients are present, creating confusion about mass source locations.

• Samples from wells can underestimate maximum concentrations by an order of magnitude or more, even with no-purge/passive sampling.

• In effect, there is little value in trying to determine contaminant mass and distribution from depth-discrete samples taken from wells. The best solution for obtaining high spatial resolution is discrete, short wells screens or multi-level sampling systems.
Multi-Level Sampling Systems

FLUTe™ Liner/Sampler

Solinst CMT® System

WestBay® System

Waterloo Multi-Level System
Advantages of Multi-Level Systems

• The high-resolution data provides a more detailed definition of complex subsurface conditions and contaminant distributions.

• Samples represent a small slice of the formation relative to the total saturated thickness to accurately identify high concentration zones.

• Multiple sampling points are less sensitive to shifts in plume location and shape over time.

• Data allows for calculation of the rate at which contaminants are moving within the formation (termed “mass flux”).
Disadvantages of Multi-Level Systems

• Initial capital cost can be very high compared to conventional well installations, often as much as 3-5 times or more.

• Analysis of multiple samples per vertical installation makes MLS systems very expensive to use for routine monitoring at “clean” sites.

• Most systems require prior experience for proper installation; manufacturer oversight is recommended for first-time users.

• Some systems may provide limited sample volume depending on hydrogeology, or may be difficult to sample at depth.
Summary

• Well purging and sampling strategies for subsurface monitoring and contaminant investigation have evolved from old water well industry methods to science-based approaches.

• Traditional well-volume purging and bailing are being displaced by low-flow sampling, passive/no-purge sampling and multi-level systems.

• There are no panaceas, and what works in some situations may not apply to others.

• Purge methods will provide flow-weighted average samples in wells when used correctly, while multi-level systems provide the best opportunity for depth-discrete samples with high spatial resolution.
Questions?

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